Response of Crops and Soils to Solid Manure Injection

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1. Introduction

Beef cattle operations have traditionally removed solid cattle manure (SCM) from feeding/holding pens and broadcast the manure on pasture and cultivated fields. The main distribution method has been to broadcast (pasture), and broadcast and eventual incorporation (cultivated fields). Some Saskatchewan cattle producers/feedlot operations have shifted to winter feeding systems that include feeding strategies such as bale grazing, swath grazing and straw/chaff pile grazing. This method maximizes the economical method of manure distribution by not having to use machinery, fuel and time to distribute the manure in the field (Jungnitsch et al., 2005). In intensive hog operations, liquid hog manure (LHM) is applied via a direct injection system. The agronomical and environmental advantages of LHM direct injection are well documented (Mooleki et al., 2002).

The expansion of the intensive livestock industry in western Canada has lead to subsequent concerns about the overloading of nitrogen (N) and phosphorus (P) nutrients in soil. In areas that receive high application rates of animal manures, elevated transport of particulate and dissolved P and N by water can be of concern in soils that are overloaded in nutrient (Carefoot and Whalen, 2003; Lee et al., 2003). For example, since the 1990's soil P levels in Manitoba have increased due to manure application and agricultural sources have been identified as responsible for supplying 15% of Manitoba's portion of the P loading into Lake Winnipeg (Barker, 2007).

Soil will retain a majority of the P and N applied as animal manure that is not removed by the crop through transformations such as immobilization, adsorption and precipitation. Soil characteristics control the forms in which P is transported from the bulk soil to surface or underground water systems (Ulen and Snall, 2007). The P mobility is strongly controlled by its chemical and physical form (Hountin et al., 2000).

Manure application method such as broadcasting and incorporation or subsurface injection of manure could have effects on the crop yield, plant N concentration and plant P concentration. The objective of this research was to examine crop yields, plant N and P uptake and soil nitrate-N and phosphorus levels as affected by different application methods of solid cattle manure (SCM).

Similar to LHM injection, SCM can now be applied using a direct injection system that utilizes a coulter opener and is “injected” into a furrow that is then closed behind the injection unit. SCM Injection will aid in reducing foul odors associated with broadcast and/or broadcast and incorporation operations. It is possible that injection of SCM will also decrease volatilization losses of N and P losses resulting from run-off. The objectives of this study were to evaluate the effect of injecting solid beef cattle manure on oat crop yield, nutrient uptake, and residual soil nutrients.

2. MATERIALS AND METHODS

2.1 General Experimental Setup

The SCM field trial was set up as a randomized complete block design. Treatments were replicated four times at Dixon. The Dixon site was established in the spring of 2007 when SCM was applied to the plots. There are two control plots for the SCM trial at Dixon, the first consisting of no manure or fertilizer being applied and no disturbance of the soil, the second control plot consisting of no manure or fertilizer being applied and disturbance of the soil using the coulter openers of the SCM injector machine.

Solid cattle manure was applied using four application procedures; 1) broadcast application where SCM is applied on the soil surface (no incorporation), 2) broadcast and incorporated where SCM is applied on the soil surface and then incorporated using a disk, 3) subsurface injection, where SCM is subsurface injected using the PAMI Solid Cattle Manure Injector Machine in six subsurface trenches by 24 inch coulter openers spaced 30 cm apart applying SCM product 10-13 cm in depth. Eighteen inch closing wheels cover the exposed injection trench with soil, 4) commercial urea fertilizer (46-0-0) is banded into the soil using a small plot drill prior to the injection of the SCM. Rate of urea fertilizer application is 78 kg N ha^{-1}) After the banding of the urea fertilizer, SCM is subsurface injected as described above.

The lowest rate of SCM being applied (1X) was equal to 100 kg total N ha^{-1}, at a rate of 20.2 tonnes ha^{-1}, and may be considered an agronomic rate in line with the amount of N that would be recommended as fertilizer manure to meet a crop requirement. Higher rates of SCM (2X = 40.4 tonnes ha^{-1}, 3X = 60.6 tonnes ha^{-1}) were considered to be double and triple the recommended agronomic rates of N fertilizer application for an application made every year.

2.2 Site Description

The SCM injection study at Dixon was established in the spring of 2007 before spring seeding operations commenced with the first applications of SCM. The experiments were initiated on the southern half of a farm field (legal location NW 21-37-23-W2) located approximately 6.5 km west of the town of Humboldt adjacent to Saskatchewan Provincial Highway #5, within the Rural Municipality of Humboldt (Figure 3.1). The soil at this site belongs to the Cudworth Association and is a Black Chernozemic soil formed in calcareous, silty, lacustrine parent materials and having a loam surface texture (Saskatchewan Soil Survey, 1989). Crops grown on the Dixon site were oats in 2007 and canola in 2008.

2.3. Experimental Design

The SCM injection trials at the Dixon site consisted of 14 treatments that were each replicated in four blocks, arranged in west to east direction. All treatments in were laid down in a randomized pattern in the spring of 2007 before the producer commenced seeding operations. The plot size of the SCM trials are 6.1 m by 6.1 m. The treatments in the SCM trials are listed in Table 2.1.

Table 2.1 Treatments in the solid cattle manure trials that were sampled for the thin section run-off study at the Dixon site.

Treatment†	Sequence	N rate	Application method
0 T ha^{-1}	control	0 kg N ha^{-1}	with no incorporation, no manure or fertilizer added
0 T ha^{-1}	control-disturbed	0 kg N ha^{-1}	with no incorporation, but disturbance
20.2 T ha^{-1}	1X	100 kg N ha^{-1}	cattle manure broadcast and incorporated
40.4 T ha^{-1}	2X	200 kg N ha^{-1}	cattle manure broadcast and incorporated
60.6 T ha^{-1}	3X	300 kg N ha^{-1}	cattle manure broadcast and incorporated
20.2 T ha^{-1}	1X	100 kg N ha^{-1}	cattle manure broadcast only
40.4 T ha^{-1}	2X	200 kg N ha^{-1}	cattle manure broadcast only
60.6 T ha^{-1}	3X	400 kg N ha^{-1}	cattle manure broadcast only
20.2 T ha^{-1}	1X	100 kg N ha^{-1}	cattle manure subsurface injected
40.4 T ha^{-1}	2X	200 kg N ha^{-1}	cattle manure subsurface injected
60.6 T ha^{-1}	3X	300 kg N ha^{-1}	cattle manure subsurface injected
20.2 T ha^{-1}	1X+U	100 kg N ha^{-1}	cattle manure subsurface injected + urea
40.4 T ha^{-1}	2X+U	200 kg N ha^{-1}	cattle manure subsurface injected + urea
60.6 T ha^{-1}	3X+U	300 kg N ha^{-1}	cattle manure subsurface injected + urea
urea fertilizer	U	78 kg N ha^{-1}	banded urea 46-0-0 fertilizer

† Application rate based on wet weight.

2.4 Manure Applications

The SCM applied in the field trial at Dixon was obtained from the Poundmaker Feedlot, which is located approximately 8 km east of the town of Lanigan, SK. The manure was applied to the appropriate plots using the PAMI Solid Cattle Manure Injector Machine mixture. Application rates of the SCM are listed in Table 2.1. The SCM was applied to the Dixon site on June 12 and 13, 2007 for the 2007 crop year. The SCM was applied to the Dixon site on May 10, 2008 for the 2008 crop year and May 20, 2009 for the 2009 crop year..

2.5 Field Soil & Plant Sampling

Plant samples were collected from the plots just prior to the producer swathing the oat crop in 2007, canola crop in 2008 and oat crop in 2009. Duplicate $1m^2$ plant samples were cut from each trial plot. Plant samples were dried, weighed (total biomass weight was recorded), thrashed and cleaned (separated into grain and straw components). The grain & straw samples were digested to determine total nitrogen (N) and phosphorus (P).

Soil samples were collected from the site in the fall of 2007, fall of 2008 and fall of 2009 following harvesting operations. Soil samples were obtained from each plot in the study using a truck mounted mechanical soil coring unit. All samples were taken to a 0-15 cm and 15-30 cm depth and analyzed for soil extractable nitrate-nitrogen (NO_3-N), and phosphorus (P) using a Technicon™ automated colorimetry analyzer.

3. RESULTS AND DISCUSSION

3.1 2007 Yields, Grain Nitrogen and Phosphorus Concentrations

In 2007, oats were grown at the Dixon site. There was a significant yield response of oats to the addition of solid cattle manure (SCM) (Figure 3.1). The highest yields were observed at the high rate (3X or 60 tonnes/hectare rate). Adding 70 lbs N/acre of urea along with the solid cattle manure gave the highest yield at the 1X rate (20 tonnes/hectare). Therefore, supplementation with urea to account for the low N availability of SCM in the year of application is a good option if one desires to use a low rate of SCM to avoid P loading.

Comparing broadcast without incorporation application to a broadcast and incorporation application, the only significant difference in yield was observed at the high rate, with the broadcast without incorporation treatment surprisingly having a higher yield (Figure 3.1). This may be related to hot and dry conditions encountered during the summer of 2007 where the mat of manure on the surface resulting from no incorporation may have reduced surface temperatures and helped reduce evaporation. Lack of a general benefit of incorporation is also likely related to the low ammonium content and low potential for volatilization losses of the N contained in the manure. For the same rate of application,

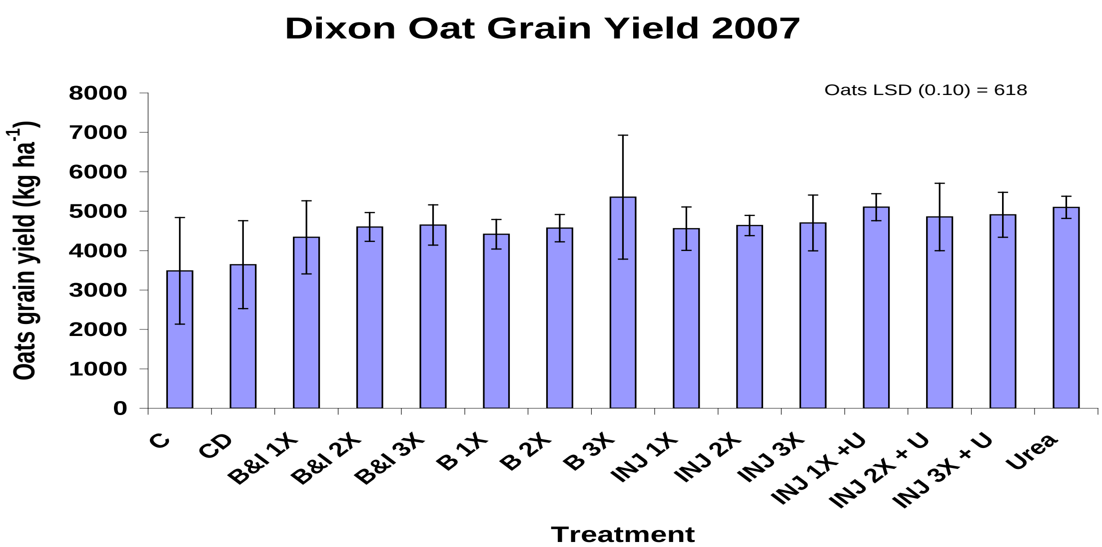

Figure 3.1 Dixon oat grain yield fall 2007.

the band injected SCM was not significantly different in yield from the broadcast and incorporate, or broadcast applications.

Grain N concentrations in the oat crop increased with increasing rate of SCM for the broadcast and incorporated, and injected treatment, but not for the broadcast without incorporation treatment (Figure 3.2). Lower plant N concentrations for the broadcast without incorporation than the other treatments suggest some lower N recovery for SCM when broadcast than when incorporated or injected. The injected SCM has grain N and straw N concentrations that are similar or slightly above the broadcast and incorporate treatments, and higher than the broadcast without incorporation. A similar trend was noted for P concentration in grain and straw, with highest P concentration in the grain in the injected treatment (Figure 3.3). Overall, there were not great differences in grain and straw nutrient concentrations between broadcast and incorporated and the band injected treatments. The highest grain and straw N concentrations were the treatments where urea was added along with the SCM.

3.2 Fall 2007 Soil Nitrogen and Phosphorus

The soil test Modified Kelowna extractable P (0-15cm) was significantly increased by the single cattle manure application (Figure 3.4). The MK extractable P increased from about 14 kg P/ha to greater than 60 kg P/ha at the highest rates of application. This effect was not observed at greater depths. The large increase in soil test P from a single application is consistent with the high P content of this manure. For the same rate of application, the broadcast without incorporation and broadcast with incorporation treatments resulted in very similar MK extractable P values. Of note is that the high rate

(3X) of injected SCM produced a significantly higher MK extractable P than the high rate of broadcast without and with incorporation. This suggests that there may be better retention of P with injected SCM when applying at high rates.

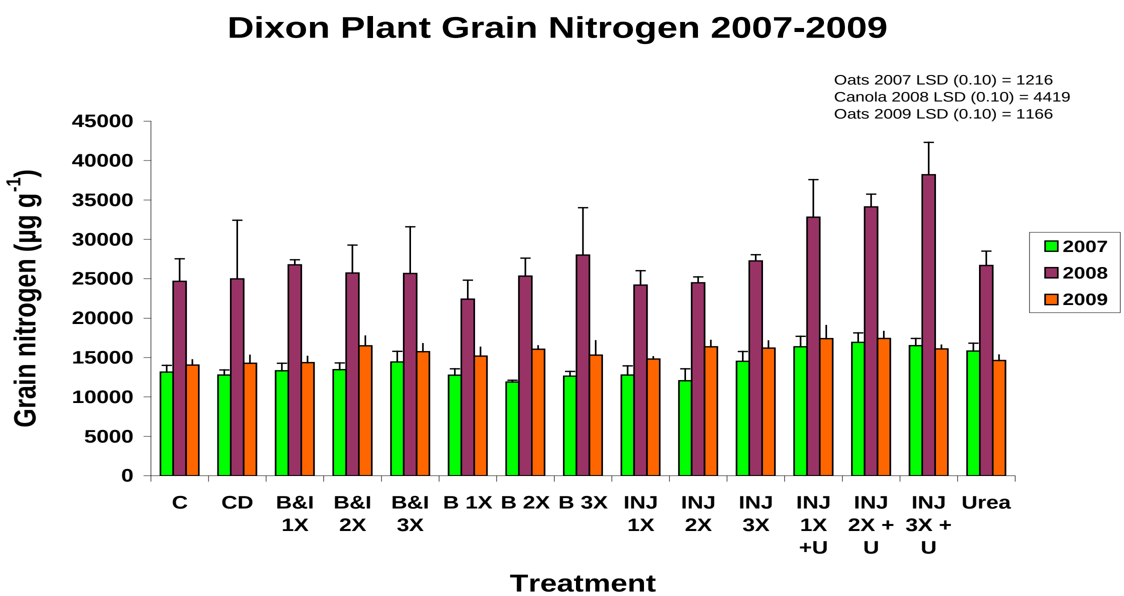

Figure 3.2 Dixon plant grain nitrogen 2007-2009.

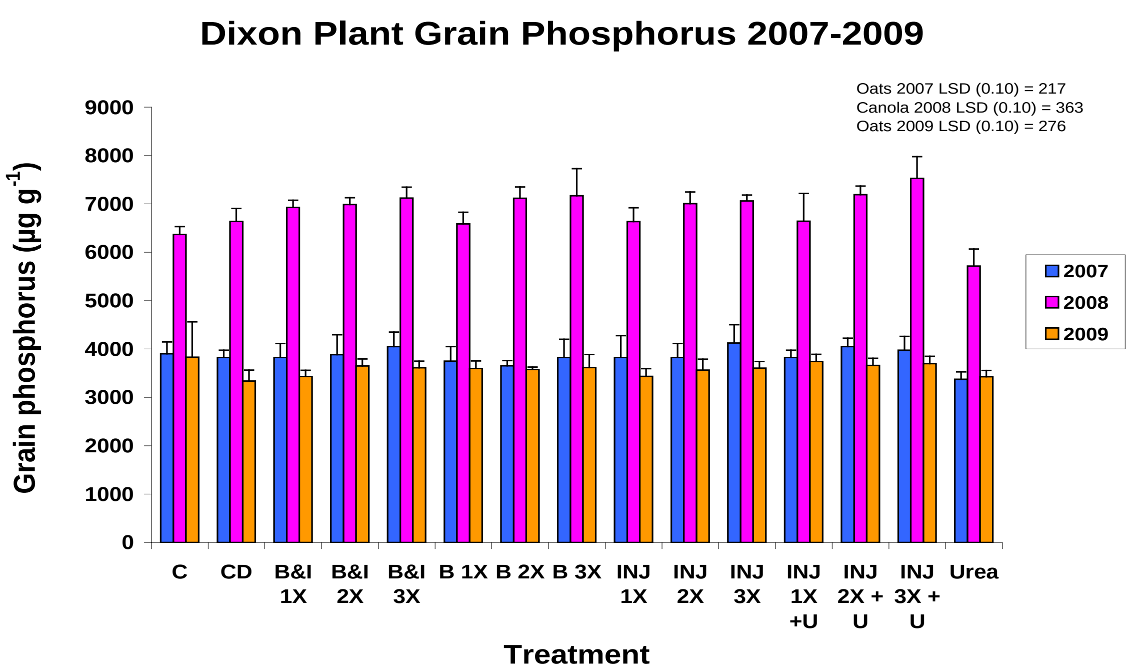

Figure 3.3 Dixon plant grain phosphorus 2007-2009.

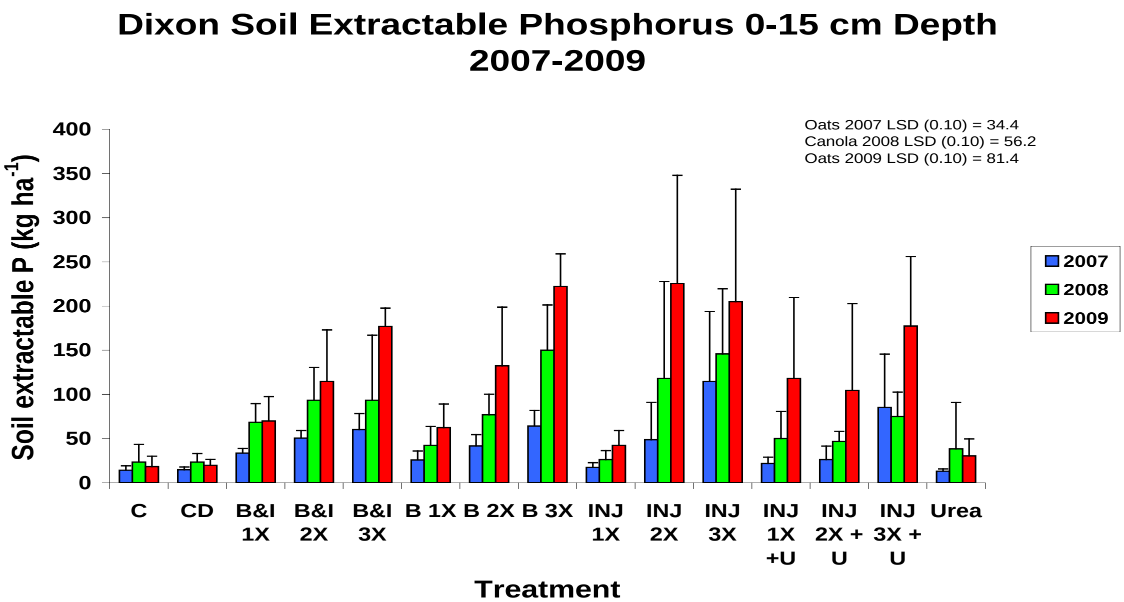

Figure 3.4 Dixon soil extractable phosphorus 0-15 cm depth 2007-2009.

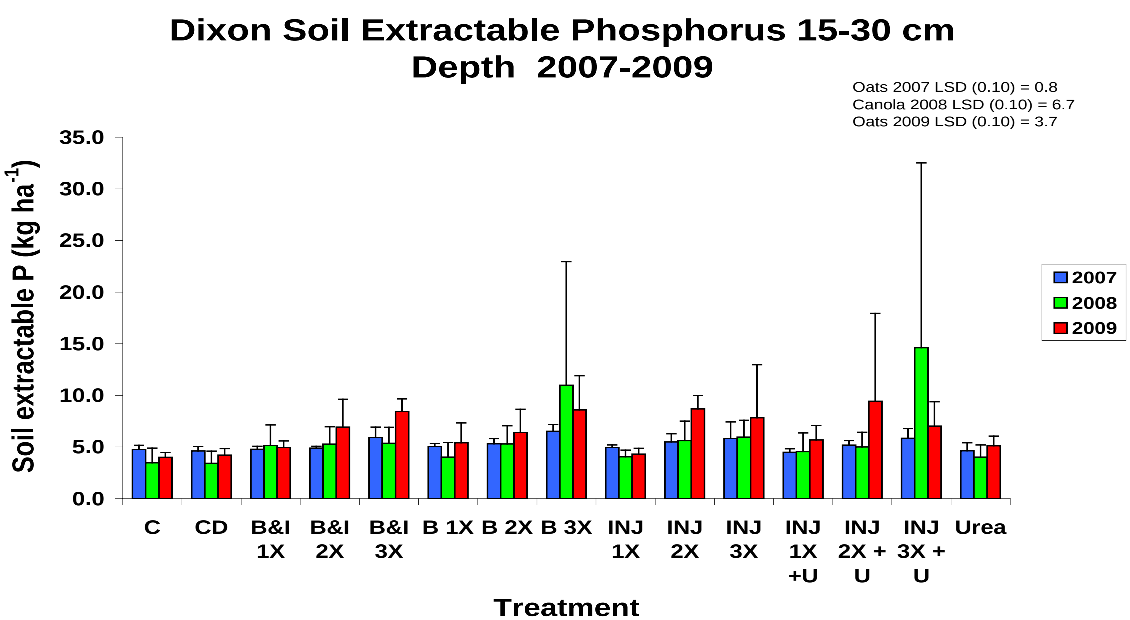

Figure 3.5 Dixon soil extractable phosphorus 15-30 cm depth 2007-2009.

The residual soil nitrate in the fall of 2007 was generally low, with not much difference between the manured treatments and the control in the 0-15 cm depth (Figure 3.6). There was no significant rate effect and little difference in residual nitrate and ammonium content among placement methods at either the 0-15 cm or 15-30 cm depth (Figure 3.7).

Overall, the highest residual nitrate contents were observed in the high rate of cattle manure injected plus urea treatment.

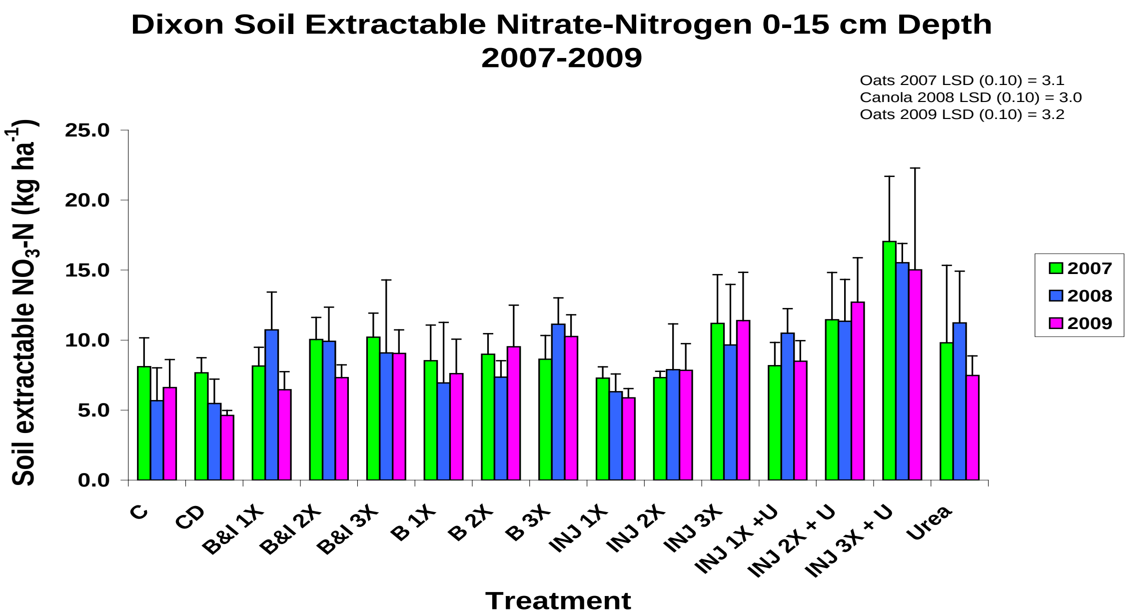

Figure 3.6 Dixon soil extractable nitrate-nitrogen 0-15 cm depth 2007-2009.

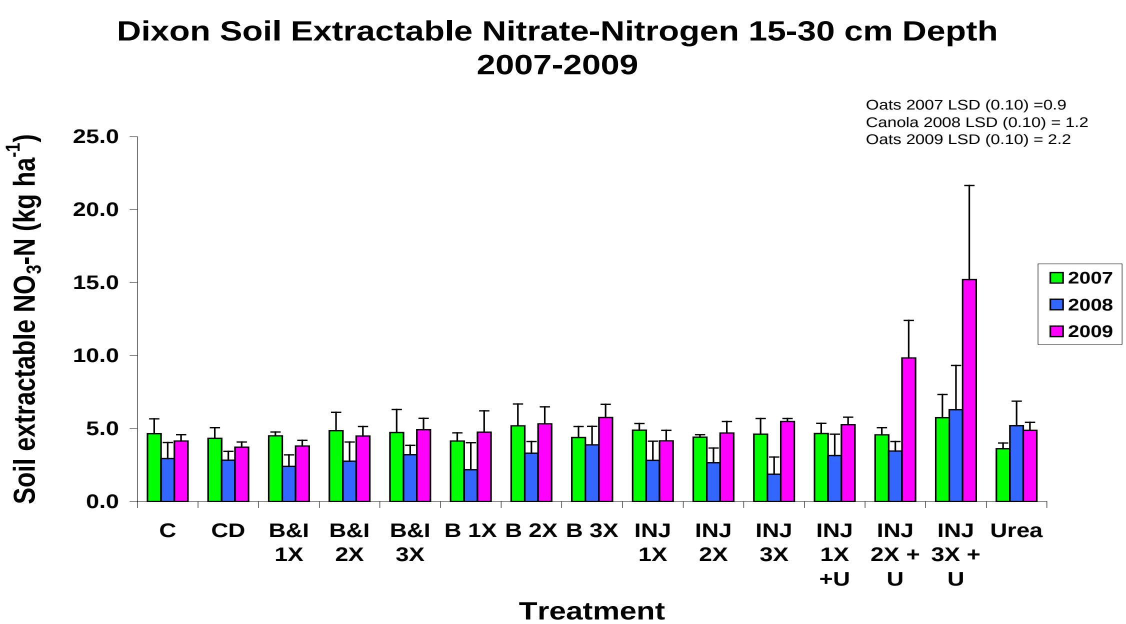

Figure 3.7 Dixon soil extractable nitrate-nitrogen 15-30 cm depth 2007-2009.

3.3 2008 Yields, Grain Nitrogen and Phosphorus Concentrations

In 2008, canola was grown at the site. Compared to the unmanured, unfertilized control treatments (control-C and control disturbed-CD), manure and urea addition increased total biomass and canola grain yield (Figure 3.8). There was no significant effect of rate of manure addition on canola yield, except for the 3X (60 tonnes/ha) injected rate that was of significantly higher yield than the 1X injected (20 tonnes/ha) rate. The greatest treatment effect was observed for combination of urea plus injected solid cattle manure. The greater response of canola yield to treatments observed in 2008 as compared to oat yield in 2007 can be explained by the greater nutrient requirement of canola compared to oats (Figure 3.8). The treatments of 70 lbs N/acre as urea plus injected cattle manure resulted in significantly higher canola yields than the other treatments, including urea alone. It is apparent that the benefit is partly from the urea providing additional plant available N that the cattle manure does not provide. It also seems that the injected manure is providing additional benefits when combined with urea, likely from the other nutrients that it contains.

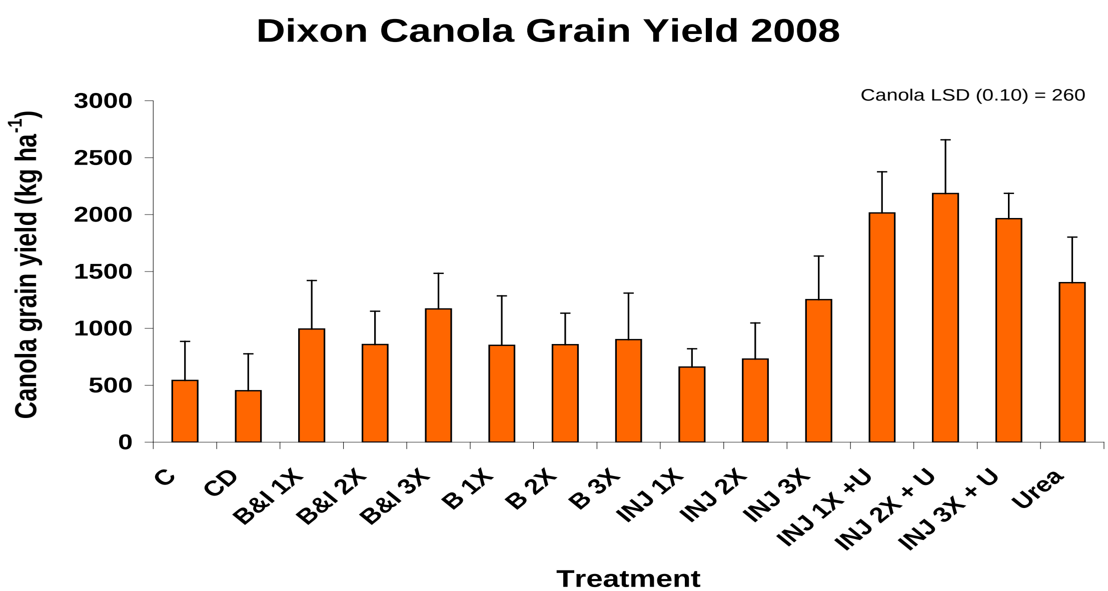

Figure 3.8 Dixon canola grain yield fall 2008.

There was no impact in 2008 of SCM manure application method on canola yield, with broadcast-no incorporation, broadcast and incorporate, and band injection producing similar yields at the same rate of application (Figure 3.8). As in 2007, lack of a general benefit of incorporation/injection is likely related to the low ammonium content and low potential for volatilization losses of the N contained in the manure.

Canola grain nitrogen content was only slightly increased by cattle manure application, reflecting the relatively low availability of N contained in the cattle manure (Figure 3.2). Both grain phosphorus and straw phosphorus were significantly increased, reflecting the significant contribution of cattle manure P to plant available P in the soil (Figure 3.3) At the 1X rate, grain and straw N concentration tended to be higher for broadcast and incorporate and injected SCM than broadcast only, indicating greater recovery of N from in-soil placement. This trend was also observed in 2007. This effect however, was not observed at higher rates. The injected SCM + urea treatment produced the highest plant N concentrations.

3.4 Fall 2008 Soil Nitrogen and Phosphorus

Manure application resulted in significant increases in MK extractable P again in the fall of 2008. After two successive manure applications, the general trend for soil test P values was to increase compared to fall of 2007, with values of ~150 kg P/ha present in the 3X treatments. There appeared to be no discernible effects of placement. Of the 3X treatments, the broadcast and the injected treatments had higher soil test P than the broadcast and incorporated in the 0-15cm depth (Figure 3.4). Adding urea to the injected manure reduced the soil test P levels in the fall, presumably due to greater yield and manure P utilization by the crop. Extractable K levels were also nearly doubled.

The soil nitrate levels in the fall of 2008 tended to increase slightly with application rate, and like in 2007 they were generally low, with only the urea treatment showing slight elevation at the 15-30 cm depth (Figure 3.7). Also, again placement had little influence on soil nitrate in the 0-15 and 15-30cm depth, with no discernable trend.

3.5 2009 Yields, Grain Nitrogen and Phosphorus Concentrations

Oats were grown on the site in 2009. A significant oat grain and straw yield response to manure addition treatments compared to the unmanured, unfertilized control treatments was observed again in 2009, as in previous years (Figure 3.9). Unlike 2007 and 2008, there was a rate effect in oat yield response in 2009, with 3X (60 tonnes/ha) manure treatments producing significantly higher oat yield than the low rate (1X). There was a response to the supplemental addition of urea at the 1X rate of manure, but not at the 2X or 3X rates. Since 2009 represents the third consecutive year on which manure was applied at these rates, it appears that sufficient mineralization of accumulated organic N in the soil is now taking place at the 2X and 3X manure rates to meet the crop nutrient requirements, especially at the 3X rate of addition. The 1X manure treatments continue to yield less than the urea treatments, indicating that supply of N from 20 tonnes/ha for 3 years is not yet sufficient to meet crop N requirements (Figure 3.9).

For the effects of placement on oat grain yield, there was little difference between surface broadcast, and broadcast and incorporation treatments at the same rate of application of cattle manure. However, there was a trend for the injected manure to yield slightly higher than the broadcast and broadcast and incorporate treatments, especially at the low rate (1X) of manure addition. In previous years (2007 and 2008), there was no apparent benefit to injection. A possible reason for the observed yield benefit of injection in 2009 (Figure 3.9) is that the in-soil injection has hastened the decomposition and

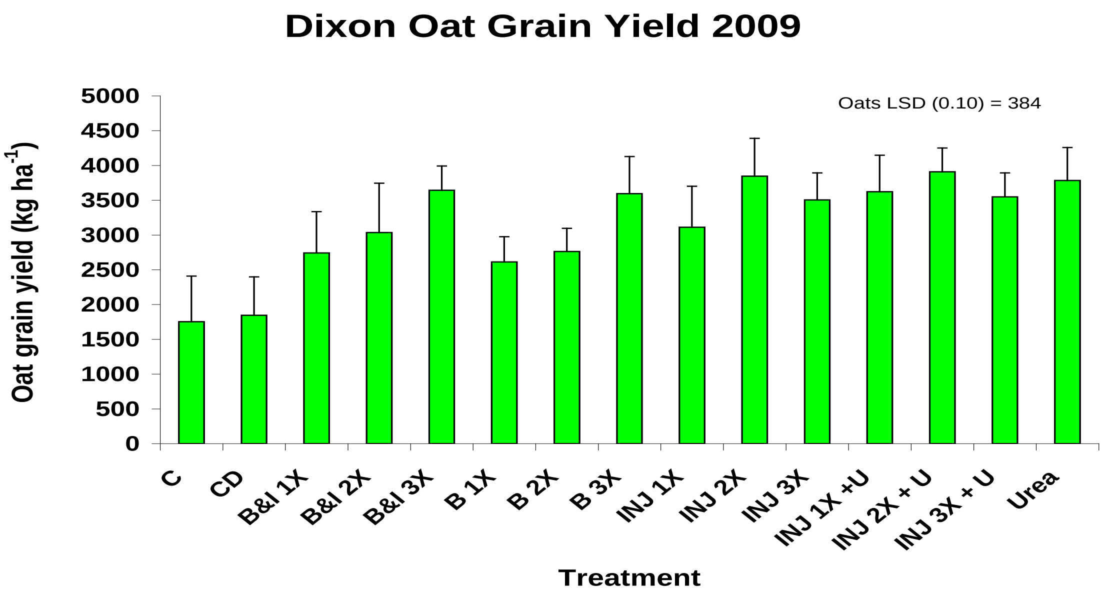

Figure 3.9 Dixon oat grain yield fall 2009.

release of available nutrients through mineralization, also supported by the increased soluble nutrient found in run-off water in this treatment. As the injection was found to reduce the concentration of nutrient at the surface (0-5cm) and increase the concentration at depth (5-10cm) compared to the other placement methods, the lower degree of stratification of nutrient in the injected treatment may also be favorable in reducing volatile losses of N to the atmosphere as ammonia as the manure undergoes decomposition.

Grain nitrogen concentrations were increased by application of cattle manure, as observed in the previous two years. The grain nitrogen concentrations in the injected treatment tended to be higher or similar to the broadcast and the broadcast and incorporate treatments, following along trends observed in 2007 and 2008 (Figure 3.2). The higher plant N concentrations along with the higher yields noted for injection, especially at the 1X rate, indicated that injection is providing some benefit in enhancing crop uptake and recovery of manure N, possibly by reducing ammonia volatilization losses or more likely enhancing decomposition to available forms. The plant P concentrations were less affected by manure application than in 2008, likely a result of the greater ability of oats to scavenge soil P compared to canola (Figure 3.3).

3.6 Fall 2009 Soil Nitrogen and Phosphorus

The soil nitrate levels in the 0-15cm depth increased with manure application, and contents generally increased with increasing rate (Figure 3.6). However the amount of nitrate in the soil, even at the high 60 tonnes/ha/yr rate, was still low (< 15 kg/ha). Also there was no evidence of significant movement of nitrate below the 15cm depth into the

15-30cm depths, except for a slight elevation at the high rates of the injected manure + urea treatment (Figure 3.7).

The largest impact of manure addition observed in this study was on soil extractable P levels, that were greatly increased by addition of manure. The soil test (modified Kelowna) P increased from 20 kg P/ha 0-15cm in the unfertilized control to > 200 kg P/ha in the 3X (60 tonnes manure/ha) treatment (Figure 3.4). This is explained by the large amount of manure P, calculated to be ~ 500 kg P/ha, added to the soil in this treatment over the three years.

These results again demonstrate that build-up of soil P can occur with cattle manure addition even over relatively short time periods when annual application rates are high. Manure placement appeared to have relatively little influence on extractable P in the 0-15cm depth. There was some small elevation in extractable P in the 15-30cm depth at high application rates, suggesting that some small amount of P may be transferred below the 0-15cm depth, perhaps as leaching of organic P, consistent with results of our P leaching studies that showed some leaching of P out of 0-15 cm intact soil cores collected from long-term cattle manure application trials (Figure 3.5).

4. Summary and Conclusions

The crop yields over the three years of the study responded positively to cattle manure addition, with the 2008 canola responding more than the oats in 2007 and 2009. Low availability of N in cattle manure due to low content of available ammonium and slow mineralization of organic N contributed to lower yields of manure treatments compared to urea. Manure addition increased grain nitrogen (protein), and phosphorus contents to a lesser extent. Highest yields and plant N concentrations were generally obtained when manure was combined with urea, in which case the crop benefited both from high availability of N added as urea and also the other nutrients such as phosphorus and sulfur that the manure supplied. N availability was increased as a result of repeated manure applications, especially at the high rate of addition.

Combination of commercial N fertilizer with cattle manure is recommended in the initial years of cattle manure addition to compensate for low N availability and to help the crops utilize the excess phosphorus that is applied as manure. There was no evidence of excessive build up of nitrate in the soil with any of the manure treatments, nor was there evidence of deep leaching below the surface layer. As expected, cattle manure addition tended to cause much greater increase in extractable soil inorganic P levels than extractable inorganic N levels and it was noted that the addition of urea along with manure helped to reduce the P accumulation in the soil.

Especially in the first two years of the study, there was little difference between broadcast, broadcast and incorporate, and band injection of the solid manure in terms of effects on crop yield. The lack of beneficial effect of in-soil placement of this manure source on crop yield may be explained by a very low content of inorganic N in the manure (ammonium) that would be susceptible to gaseous loss by volatilization and thereby benefit from in-soil placement. There was some evidence for slightly increased recovery of added N and P in manure when it was placed in the soil as injected or incorporated versus broadcast.

In the last year of the study, 2009, there appears to be some additional benefit of the injection method of placement over the other two methods on yield, especially at the low rate of application. This was also observed in higher plant N concentrations and uptake of N observed in the oats grown in the third year of the study. This may be explained by the injection enhancing the decomposition of the manure to plant available inorganic forms deeper down (10-15cm depth) in the soil profile that the roots can access better. Overall, for this manure source at this location, the agronomic benefits of in-soil placement of the solid manure on agronomic performance were relatively limited, especially in the initial years, and may not justify the extra associated costs.

4. Cited References

Barker, B. 2007. Managing phosphorus based manure inputs. Top Crop Manager. December 2007. 33:

Carefoot, J. P. and J.K.Whalen. 2003. Phosphorus concentrations in subsurface water as influenced by cropping systems and fertilizer sources. Can. J. Soil Sci. 83: 203–212.

Hountin, J.A., A. Karam, D. Couillard[c] and M. P. Cescas. 2000. Use of a fractionation procedure to assess the potential for P movement in a soil profile after 14 years of liquid pig manure fertilization . Agric., Ecosystems & Environment. 78: 77-84.

Jungnitsch, P., H. Lardner, J. Schoenau, and T. Highmoor. 2005. Effects of winter feeding systems on cow performance, feeding site soil nutrients and pasture growth. J. of Animal Sci. 83: 247-247.

Mooleki, S.P., Schoenau, J.J., Hultgreen, G., Wen, G., and Charles, J.L. 2002. Effect of rate, frequency and method of liquid swine manure application on soil nitrogen availability, crop performance and N use efficiency in east-central Saskatchewan. Canadian J. of Soil Sci. 82(4): 457-467.

Lee, S.I., S.Y. Weon, C.W. Lee and B. Koopman. 2003. Removal of nitrogen and phosphate from wastewater by addition of bittern. Chemosphere. 51:265-271.

Saskatchewan Soil Survey. 1989. Rural Municipality of Humboldt No. 370. Preliminary soil map and report. Saskatchewan Institute of Pedology, University of Saskatchewan, Saskatoon, SK, Canada.

Ulen, B and S. Snäll. 2007. Forms and retention of phosphorus in an illite-clay soil profile with a history of fertilization with pig manure and mineral fertilizers. Geoderma. 137: 455–465.